PRTN 273

Some Results on a Simulation Study of CAP4.9 Transmission Scheme

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I. Introduction

In PRTN #265, Jil Westcott of BBN pointed out that the FIFO transmission scheme used for the PRU may be inefficient. According to that transmission scheme, a PRU would allow at most one packet unacknowledged at any one time regardless for which neighboring PRU the packet is intended. A second packet would not be transmitted until the first packet is either properly acknowledged, or dropped after a maximum number of retransmissions. Westcott suggested to allow more than one unacknowledged packets simultaneously outstanding. In CAP 4.9, a transmission scheme, often referred to as the cyclic transmission scheme, is constructed. This transmission scheme allows more than one packet to be simultaneously unacknowledged, but at any one time there may be at most one outstanding packet intended for each neighboring PRU.

In this PRTN, we report some simulation results on a study of the CAP 4.9 transmission scheme, using the building-block simulator [PRTN#268]. The results presented include the

throughput improvement of the CAP4.9 transmission scheme over the FIFO transmission scheme, the effects of success transmission probabilities, and of the initial transmission delay, RTXDLY. First, we describe the simulation model and the parameters used. We then present and discuss the simulation results.

II. The Building-Block Simulation Model

The building-block simulator simulates the functions of one PRU. A PRU is modeled as consisting of two servers in series: a processor and a transmitter (Figure 1). The input, or 'received', traffic is of Poisson distribution with a constant packet length of 17 words (i.e., 272 bits). Upon arrival they form a queue for processing, and a queue for transmission after the completion of processing. The total number of buffers for these two queues is limited by the size of the common buffer pool, which is set at 5. Packets received are placed in the processing queue. According to preassigned probabilities, each packet is assigned a 'previous PRU' ID and a 'next PRU' ID. The previous PRU is the PRU from which the packet is to have been received; and the next PRU is the PRU to which this packet is to be forwarded. A zero next PRU ID indicates that this received packet is not intended for the receiving PRU. Throughout this study, we evenly distribute the intended packets among the next PRUs. Depending on whether it is intended, a packet after being received incurs a processing delay from one of two distributions. In this study, the processing times for intended and unintended packets are exponentially distributed with means

equal to 10 msec and 3 msec respectively.

After being processed, an intended packet is ready for transmission. After a packet has been transmitted, the PRU waits a specified time out period for an acknowledgement. The time out periods, i.e., the transmission and retransmission delays, are structured the same as in CAP 4, based on the current default values for RTXDLY (8.2 msec) and RETXDY (10.24 msec). The CSMA channel access mode is simulated by a random number of channel sensings, with a range of [1, 5], and a random delay between two channel sensings, with a range of (0.5, 2] msec. After the transmission of a packet, an acknowledgement may be received in an exponentially distributed next-hop turn-around time (NRT). A probability (FTSP), as a function of the neighboring PRU, is assigned to the successful transmission of a forwarded packet; also, a probability is assigned to the successful transmission of the returning acknowledgement. If an acknowledgement is not received before the expiration of the time out period, a retransmission would take place then, unless the processor is busy. A maximum number of transmissions for each packet is set at 6. (Since only one PRU is simulated, actual alternate routing is not an issue.)

III. Results and Discussions

The simulation program used in this study was designed as the building-block of the system-level simulation described in PRTN #268. This building-block simulator has demonstrated behaviour in close correlation with that observed in the measurement

experimental results, when used stand-alone it cannot fully reflect dynamic interaction among the PRUs. The reader is cautioned to take the results presented here as relative comparisons between different schemes and parameter values.

The statistics collected are cumulative over all neighbors. They include: the one-hop delay (from the arrival of a packet at the simulated PRU to its successful arrival at the next PRU), the throughput (the number of packets successfully transmitted to the next PRU), the buffer occupancy, the number of dropped (after a maximum number of retransmissions) and discarded packets (due to buffer overflow), the previous-hop acknowledgement time (time elapsed from the arrival of a packet until the successful transmission of its first acknowledgement to the previous PRU), and the next-hop acknowledgement time.

In this report, the behaviour of a PRU is presented based upon the one hop throughput-delay relations for the traffic passing through that PRU. Due to the operational nature of the PRU, the traffic of two neighboring PRUs in a PRNET are highly correlated. How do they actually correlate depends upon the network configuration, the traffic pattern, as well as other factors. Due to this correlation, the behaviour of a PRU in a network depends a great deal on the operating points of its neighboring PRUs. In particular, an increase in the throughput of a PRU usually implies higher traffic to its neighbors. It may therefore take longer for a neighb to acknowledge packets intended for him. In turn, such higher acknowledgement time may cause higher delay and lower throughput for this PRU. While simulating a single PRU, only limited above mentioned dynamic interaction between neighboring PRUs can be taken into account.

For comparison purpose, we define an equilibrium trace along which the average next-hop acknowledgement time (NAT), and the average previous-hop acknowledgement time (PAT) are equal. Such a trace defines a 'maximum traffic', or 'capacity', of a PRU. we will use this 'capacity' for comparison. Such a trace may be interpreted as describing the steady state throughput-delay relation of a PRU with all its neighbors operating at the same operating point as its own.

For graph presentation, we show the comparison of the traces as well as the contruction of each trace from a set of throughput-delay curves, each with a different next hop turn-around time.

1. Comparison of ~~Cyclic~~ CAP 4.9 vs FIFO Transmission Schemes

Conceptually, the CAP 4.9 transmission scheme implements multiple independent FIFO transmit queues. Only the packets on the top of a FIFO queue may be transmitted. In this view of the CAP 4.9 transmission scheme, the FIFO transmission becomes its special case of one FIFO queue.

The advantage of CAP 4.9 transmission scheme over the FIFO transmission scheme increases with the number of neighboring PRUs. This advantage reaches a limit when the number of neighbors becomes much greater than the number of buffers available. In which case, the likelyhood of two packets for the same neighbor waiting in the queue for transmission vanishes. The simulation results presented in Figure 6 indicate that significant improvement can be achieved by CAP 4.9 cyclic transmission. Using the above defined measure, we have observed about 72% improvement over FIFO with 2 neighbors, 132% with 3 neighbor,

and 184% with 4 neighbors.

2. The Effect of Success Transmission Probability

The 'Hidden terminal' effect has been a concern when CSMA is used for multi-hop packet radio networks. The effect of 'hidden terminals' is that the advantage of CSMA over ALOHA channel access mode may be significantly reduced due to higher collision rate among packets from mutually hidden PRUs. In our study, the collision rate is translated into the success transmission probability. To investigate the extend of the adversity due to the 'hidden terminal' effect, we ran the building-block simulator with varying success transmission probability. The conclusion one may draw from the results presented in Figure 9 is that a lower success transmission probability would not significantly affect the PRU performance. This is because the failure probability diminishes exponentially with the number of retransmissions. The retransmissions may increase the traffic delay. But the system appears to become saturated due to other factors before the effect of 'hidden terminals' becomes significant. This observation coincides with our previous measurement experience that channel does not seem to be the bottle-neck of the system.

3. The Impact of Reducing Initial Transmission Delay (RTXDLY)

In the Hop-by-Hop measurement experiment, we observed that the default values for RTXDLY and RETXDY may not be set at their optimum. It indicated that RTXDLY, the initial transmission delay, should be reduced. Recently, we also heard the argument

that giving priority to the first transmission of a packet may improve PRNET performance. This argument is well shared. The CAP4.9 transmission scheme and the subsequent CAP 5 transmission scheme also reflects such view. Reducing the value of RTXDLY, the initial transmission delay, may be another step along the same direction. Although some improvement by reducing RTXDLY is expected, it is surprising to observe its extent of improvement indicated by our simulation results shown in Figure 11. In the case of 3 neighbors, by reducing RTXDLY from 8.2 msec to 3.5 msec an improvement of 43% is observed. Although this result is not definitive, it may indicate that a varification by measurement is warranted.

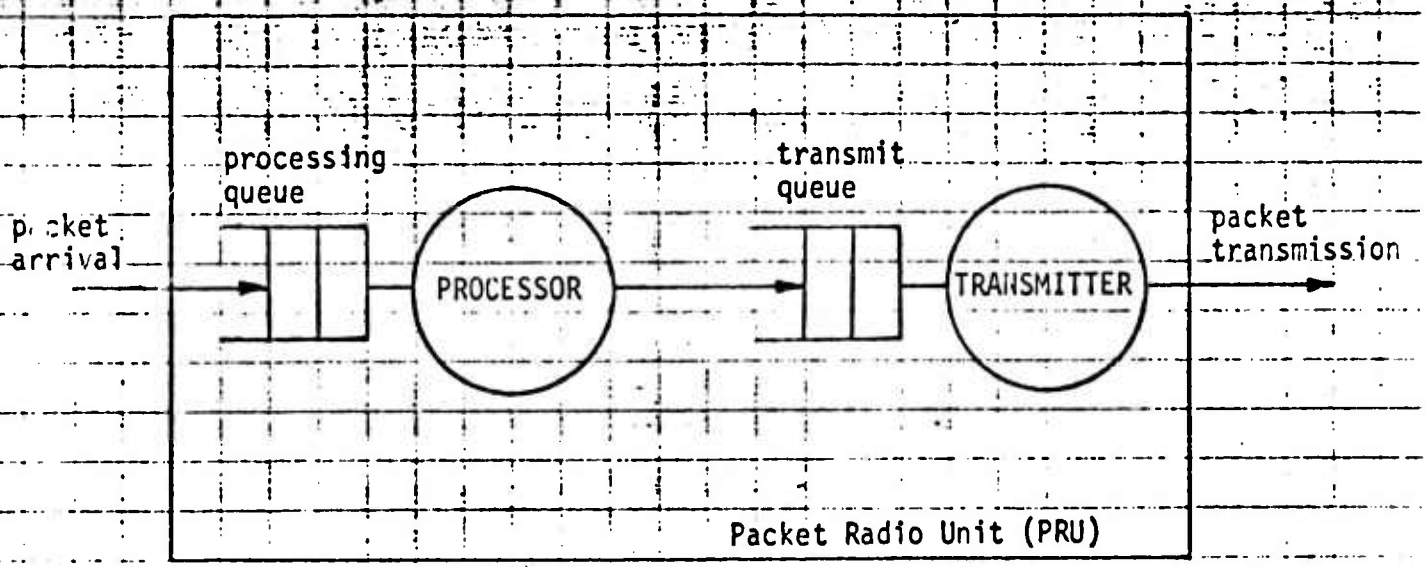
processing
queue
transmit
queue
packet
arrival
PROCESSOR
TRANSMITTER
packet
transmission
Packet Radio Unit (PRU)

Figure 1

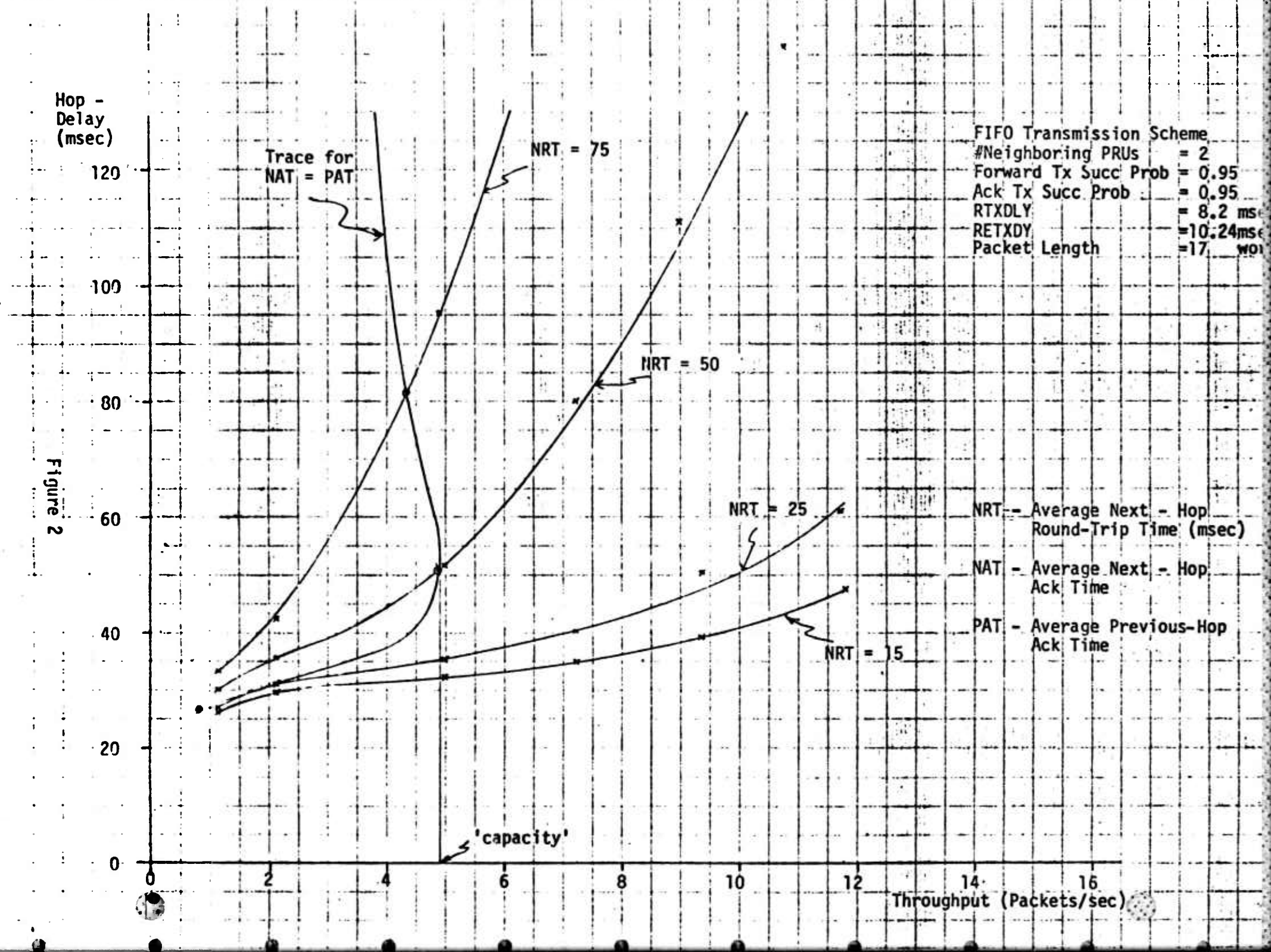
Hop - Delay (msec)
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
Throughput (Packets/sec)
Trace for NAT = PAT
NRT = 75
NRT = 50
NRT = 25
NRT = 15
'capacity'
FIFO Transmission Scheme
#Neighboring PRUs = 2
Forward Tx Succ Prob = 0.95
Ack Tx Succ Prob = 0.95
RTXDLY = 8.2 ms
RETXDY =10.24ms
Packet Length =17 wo
NRT -- Average Next - Hop Round-Trip Time (msec)
NAT - Average Next - Hop Ack Time
PAT - Average Previous-Hop Ack Time

Figure 2

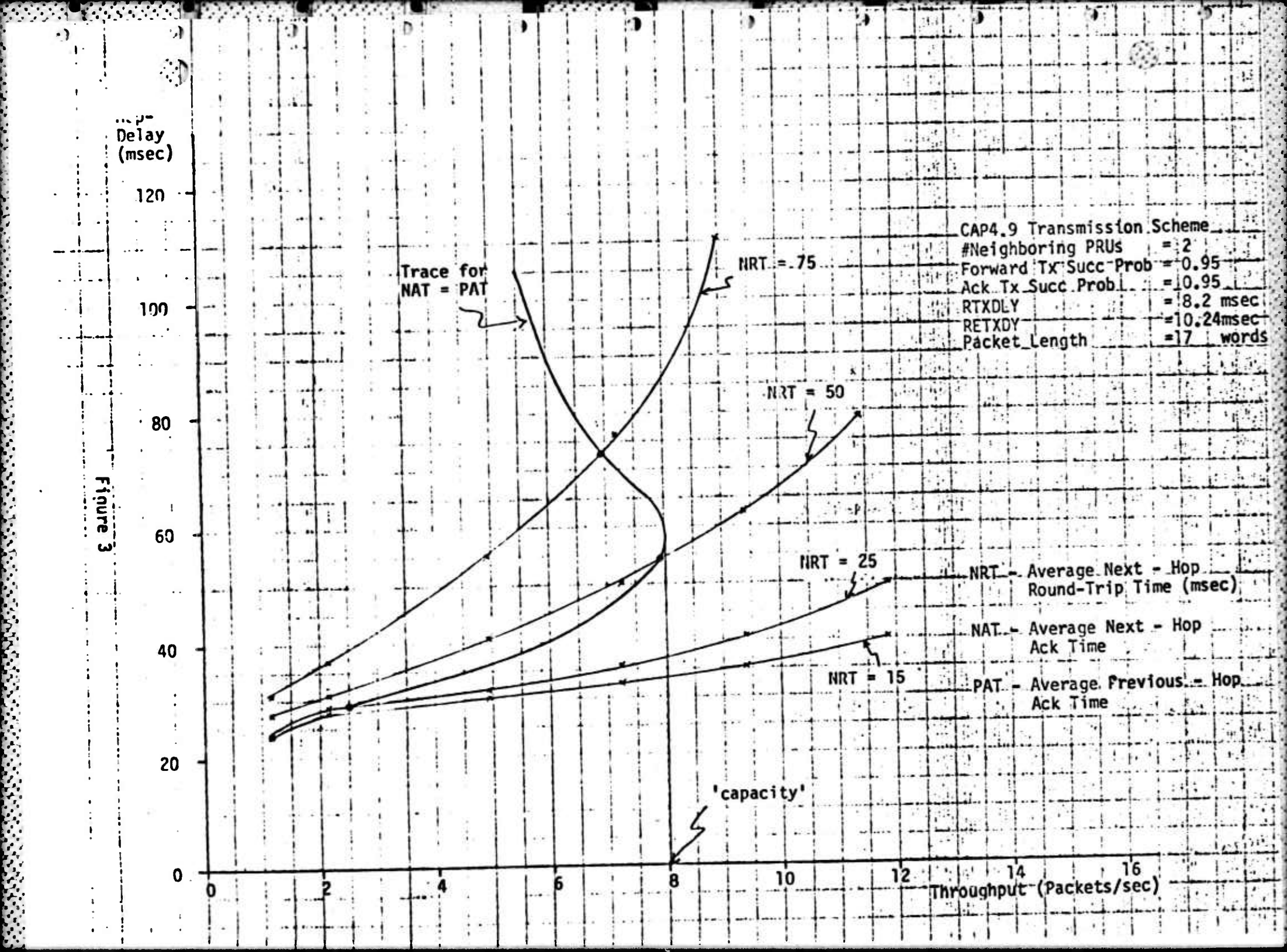
Delay (msec)
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
Throughput (Packets/sec)
Trace for NAT = PAT
NRT = 75
NRT = 50
NRT = 25
NRT = 15
'capacity'
CAP4.9 Transmission Scheme
#Neighboring PRUs = 2
Forward Tx Succ Prob = 0.95
Ack Tx Succ Prob = 0.95
RTXDLY = 8.2 msec
RETXDY = 10.24msec
Packet Length = 17 words
NRT - Average Next - Hop Round-Trip Time (msec)
NAT - Average Next - Hop Ack Time
PAT - Average Previous - Hop Ack Time

Figure 3

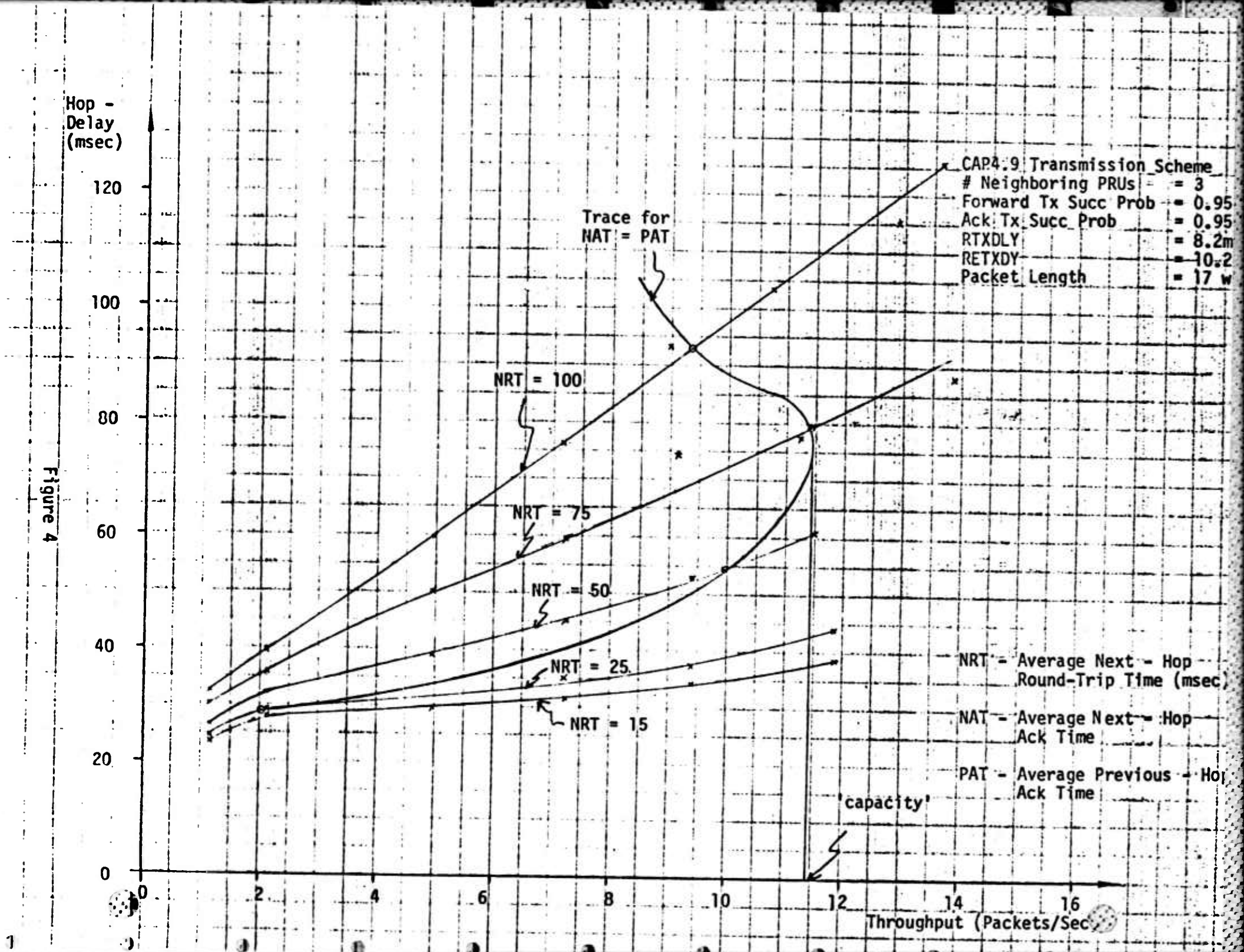
Hop - Delay (msec)
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
Throughput (Packets/Sec)
CAP4.9 Transmission Scheme
Neighboring PRUs = 3
Forward Tx Succ Prob = 0.95
Ack Tx Succ Prob = 0.95
RTXDLY = 8.2m
RETXDY = 10.2
Packet Length = 17 w
Trace for NAT = PAT
NRT = 100
NRT = 75
NRT = 50
NRT = 25
NRT = 15
'capacity'
NRT - Average Next - Hop Round-Trip Time (msec)
NAT - Average Next - Hop Ack Time
PAT - Average Previous - Hop Ack Time

Figure 4

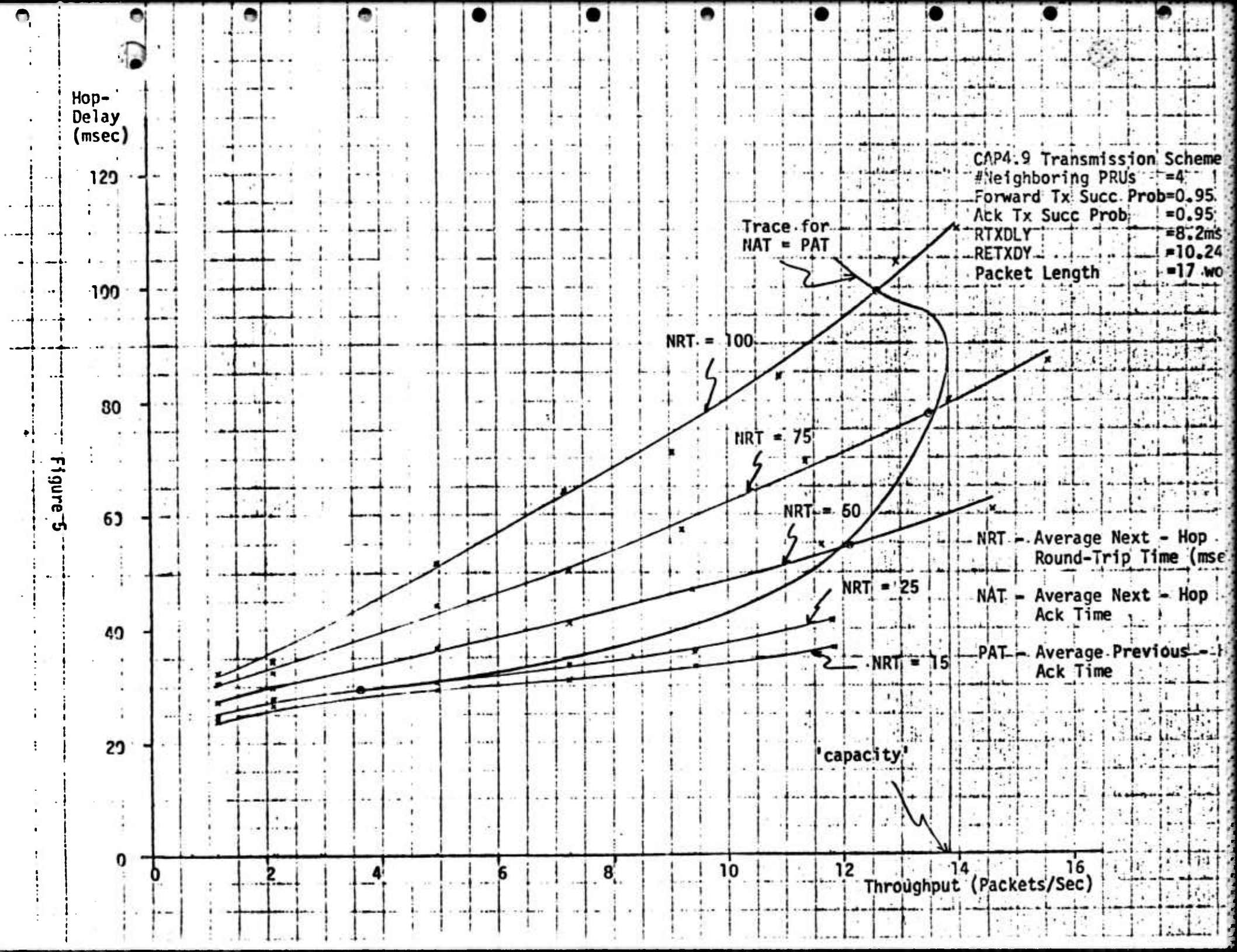
Hop-
Delay
(msec)
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
Throughput (Packets/Sec)
CAP4.9 Transmission Scheme
#Neighboring PRUs =4
Forward Tx Succ Prob=0.95
Ack Tx Succ Prob =0.95
RTXDLY =8.2ms
RETXDY =10.24
Packet Length =17 wo
Trace for
NAT = PAT
NRT = 100
NRT = 75
NRT = 50
NRT = 25
NRT = 15
'capacity'
NRT - Average Next - Hop
Round-Trip Time (mse
NAT - Average Next - Hop
Ack Time
PAT - Average Previous -
Ack Time

Figure 5

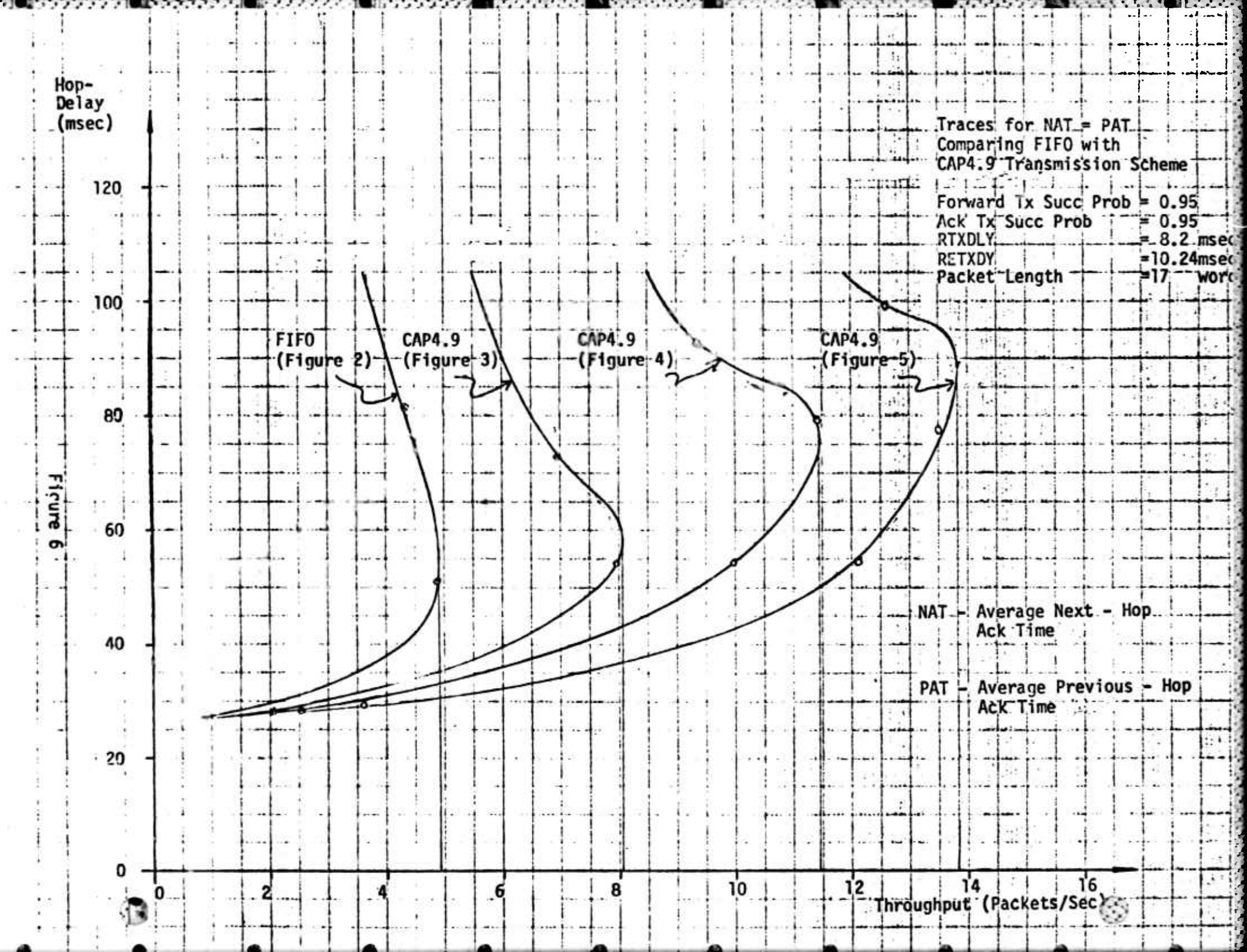
Hop-
Delay
(msec)
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
Throughput (Packets/Sec)
FIFO
(Figure 2)
CAP4.9
(Figure 3)
CAP4.9
(Figure 4)
CAP4.9
(Figure 5)
Traces for NAT = PAT
Comparing FIFO with
CAP4.9 Transmission Scheme
Forward Tx Succ Prob = 0.95
Ack Tx Succ Prob = 0.95
RTXDLY = 8.2 msec
RETXDY =10.24msec
Packet Length =17 word
NAT - Average Next - Hop
Ack Time
PAT - Average Previous - Hop
Ack Time

Figure 6

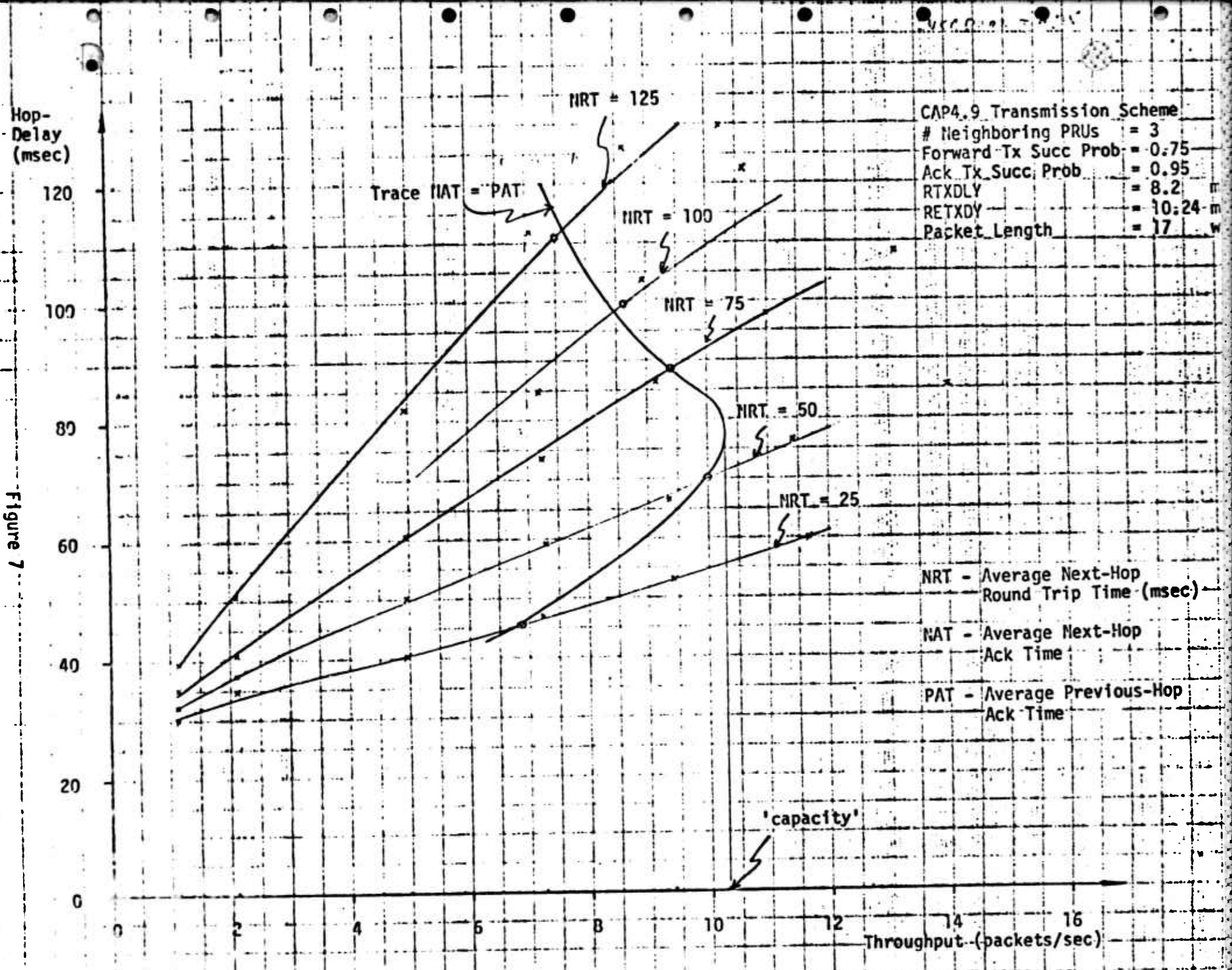
Hop-Delay (msec)
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
Throughput (packets/sec)
NRT = 125
Trace NAT = PAT
NRT = 100
NRT = 75
NRT = 50
NRT = 25
'capacity'
CAP4.9 Transmission Scheme
Neighboring PRUs = 3
Forward Tx Succ Prob = 0.75
Ack Tx Succ Prob = 0.95
RTXDLY = 8.2 m
RETXDY = 10.24 m
Packet Length = 17 w
NRT - Average Next-Hop Round Trip Time (msec)
NAT - Average Next-Hop Ack Time
PAT - Average Previous-Hop Ack Time

Figure 7

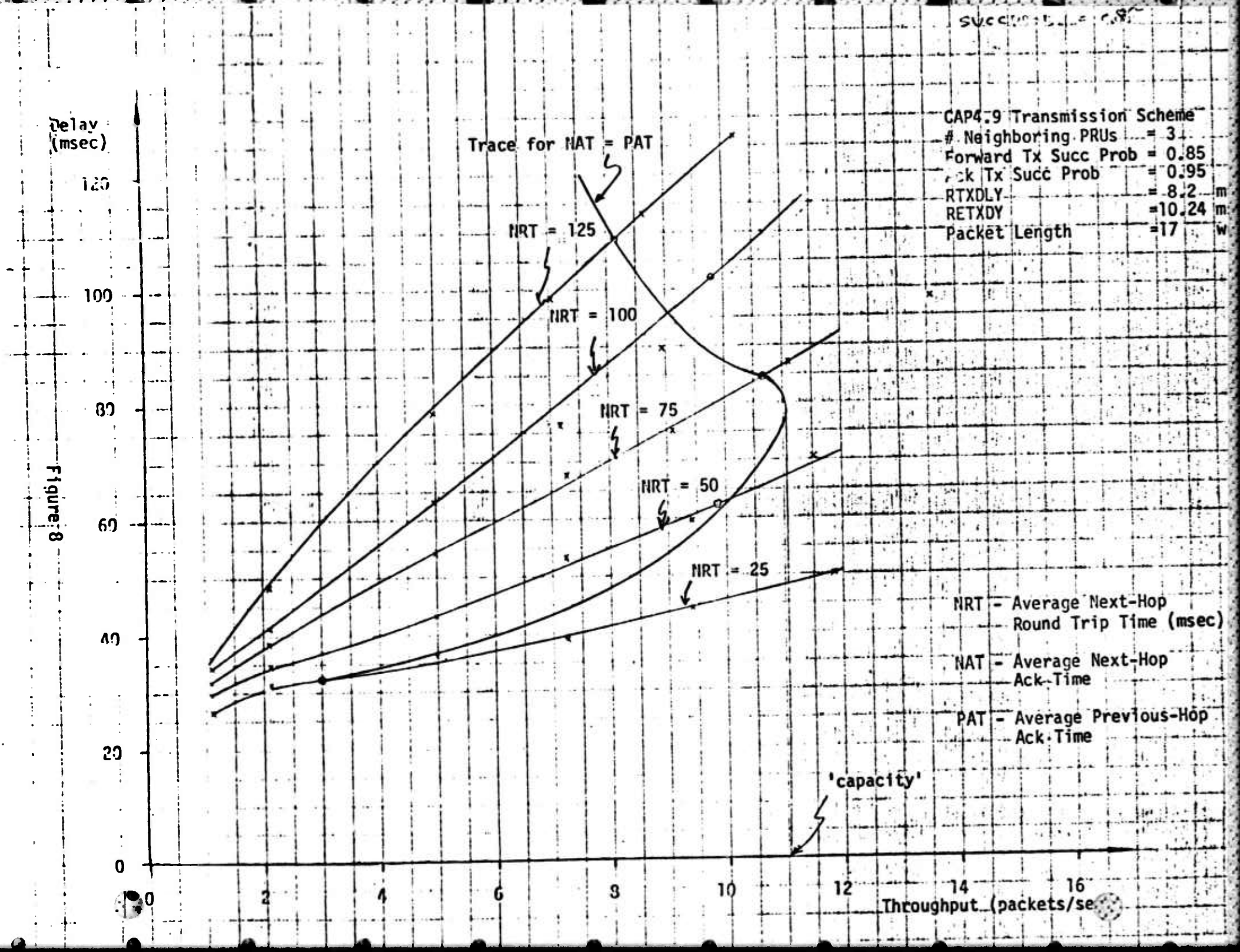
Delay (msec)
120
100
80
60
40
20
0
Trace for NAT = PAT
NRT = 125
NRT = 100
NRT = 75
NRT = 50
NRT = 25
'capacity'
0
2
4
6
8
10
12
14
16
Throughput (packets/se
CAP4.9 Transmission Scheme
Neighboring PRUs = 3
Forward Tx Succ Prob = 0.85
Ack Tx Succ Prob = 0.95
RTXDLY = 8.2 m
RETXDY =10.24 m
Packet Length =17 w
NRT - Average Next-Hop Round Trip Time (msec)
NAT - Average Next-Hop Ack-Time
PAT - Average Previous-Hop Ack-Time

Figure 8

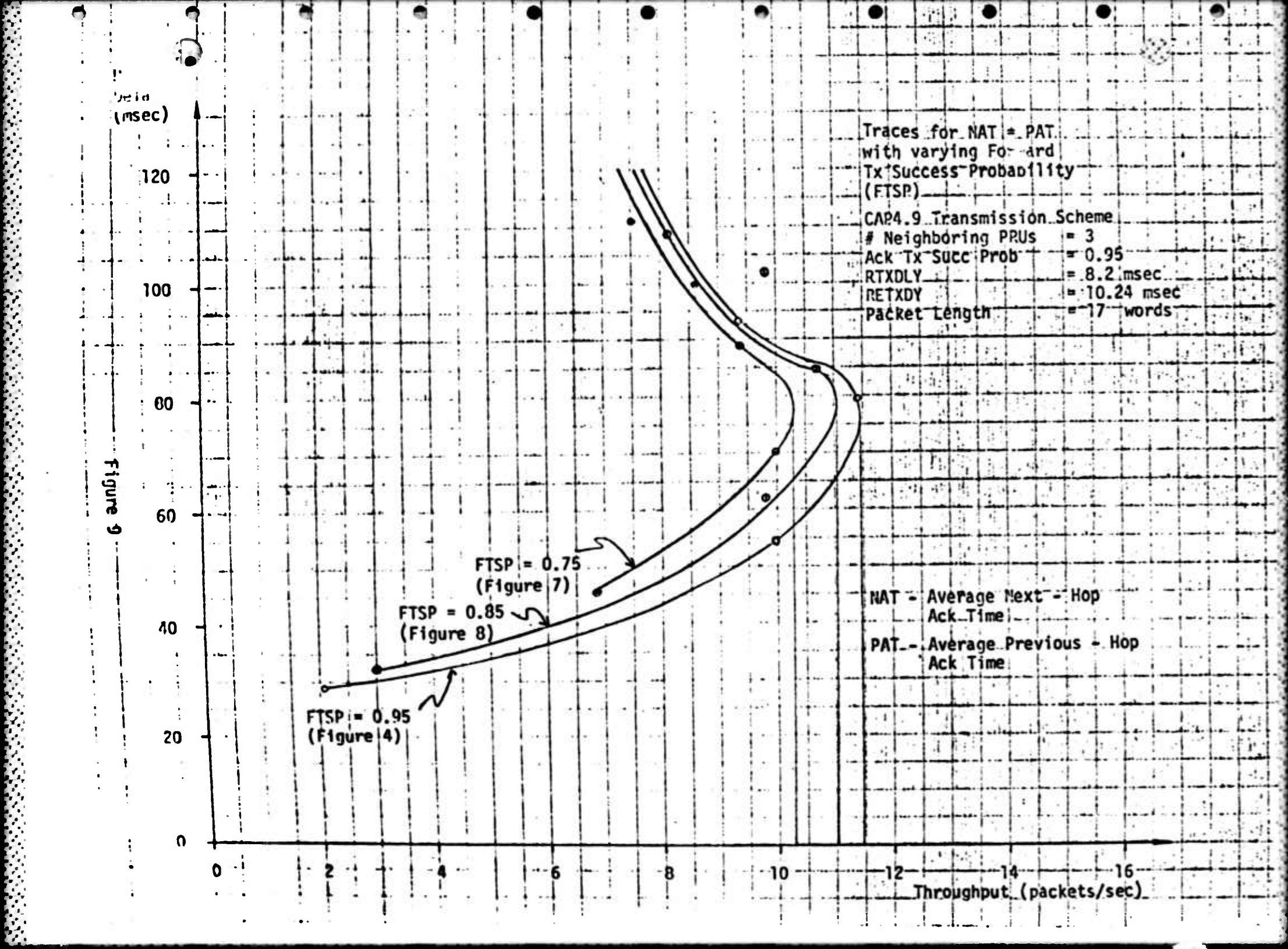
(msec)
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
Throughput (packets/sec)
Traces for NAT = PAT
with varying Forward
Tx Success Probability
(FTSP)
CAP4.9 Transmission Scheme
Neighboring PRUs = 3
Ack Tx Succ Prob = 0.95
RTXDLY = 8.2 msec
RETXDY = 10.24 msec
Packet Length = 17 words
FTSP = 0.75
(Figure 7)
FTSP = 0.85
(Figure 8)
FTSP = 0.95
(Figure 4)
NAT - Average Next - Hop
Ack Time
PAT - Average Previous - Hop
Ack Time

Figure 9

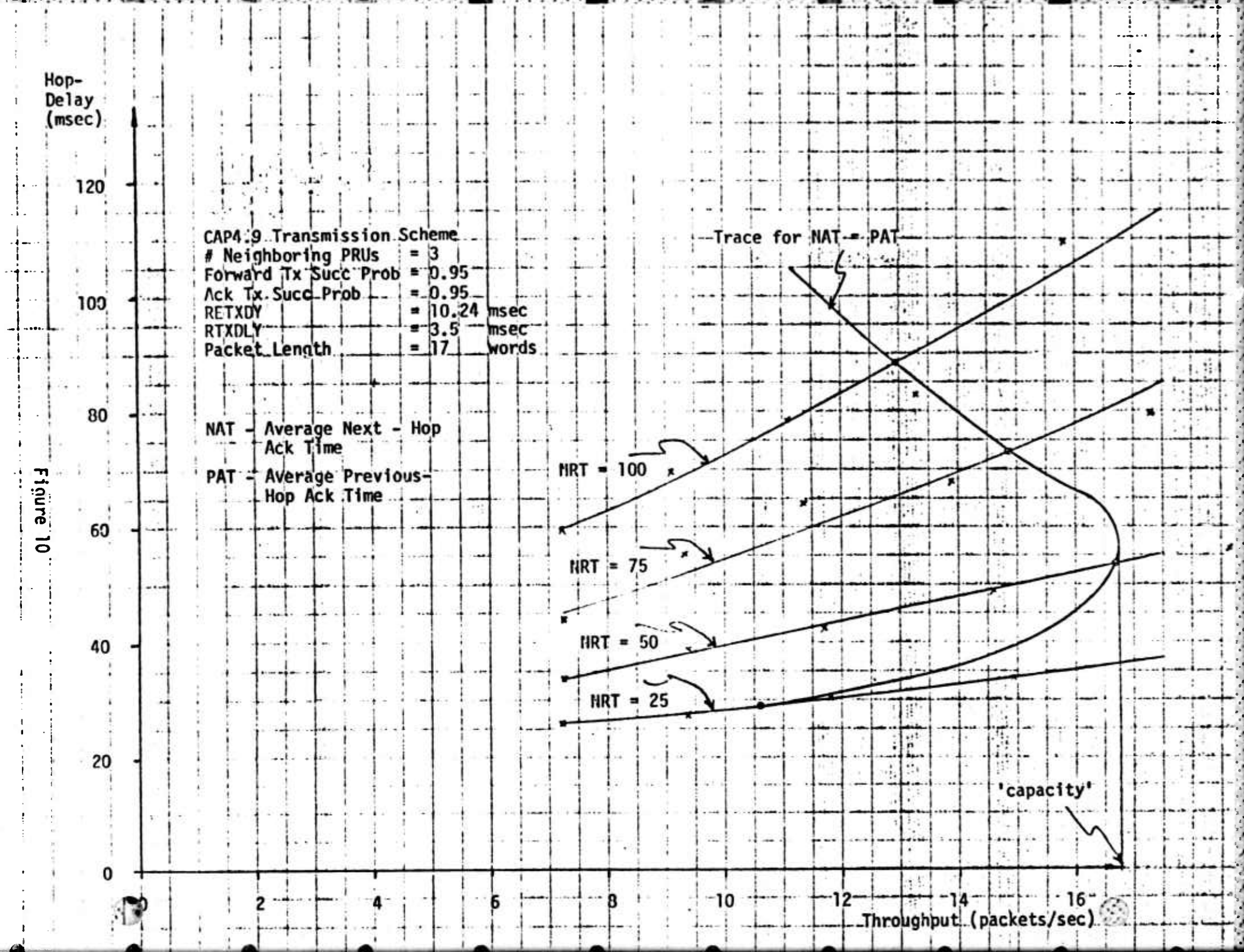
Hop-
Delay
(msec)
120
100
80
60
40
20
0
CAP4.9 Transmission Scheme
Neighboring PRUs = 3
Forward Tx Succ Prob = 0.95
Ack Tx Succ Prob = 0.95
RETXDY = 10.24 msec
RTXDLY = 3.5 msec
Packet Length = 17 words
NAT - Average Next - Hop
Ack Time
PAT - Average Previous-
Hop Ack Time
Trace for NAT = PAT
MRT = 100
MRT = 75
MRT = 50
MRT = 25
'capacity'
0
2
4
6
8
10
12
14
16
Throughput (packets/sec)

Figure 10

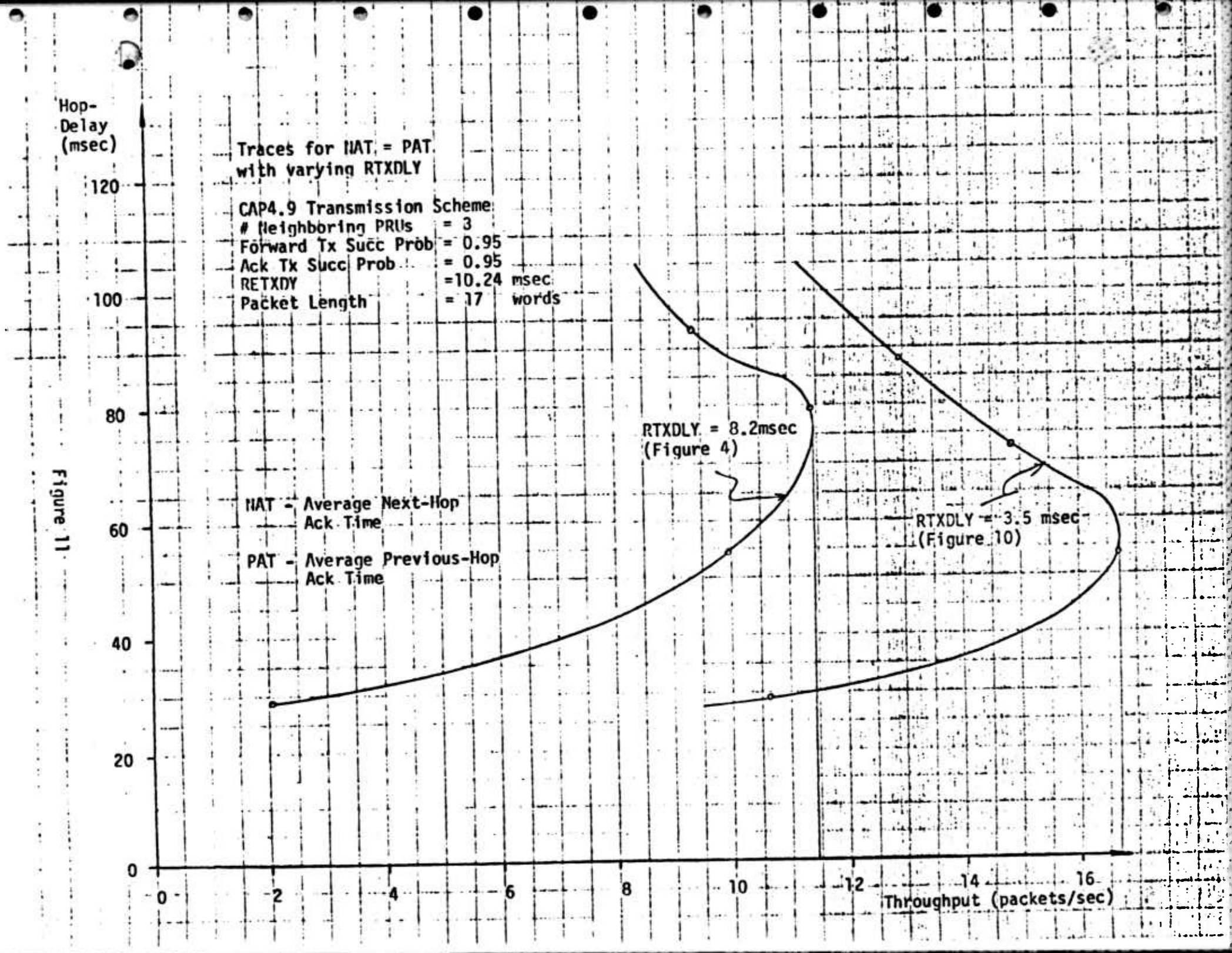
Hop-Delay (msec)
Traces for NAT = PAT with varying RTXDLY
CAP4.9 Transmission Scheme
Neighboring PRUs = 3
Forward Tx Succ Prob = 0.95
Ack Tx Succ Prob = 0.95
RETXDY =10.24 msec
Packet Length = 17 words
RTXDLY = 8.2msec (Figure 4)
RTXDLY = 3.5 msec (Figure 10)
NAT - Average Next-Hop Ack Time
PAT - Average Previous-Hop Ack Time
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
Throughput (packets/sec)

Figure 11